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The Efficiency of a Trapezoid-shaped Solar Still

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ABSTRACT

Drinking water is scarce in developing countries and is becoming a limiting resource for the entire world. This experiment focuses on the enhancement of a solar purification model known as a solar still. The improvement of the solar still will make purifying water a viable option in poor areas of the world and the solar still will reduce the amount of water purified using petroleum-based energy sources and help temper the ongoing water crisis. A solar still model with a polyethylene top and a mirror inside was tested for three hours on three different days and the purified water measured. The model barely yielded results, with only one of the three days producing a measurable amount of water. While the tests yielded very little purified water, the model did evaporate a significant amount of water, which could mean that by fixing a small design flaw, this system could be a solution to water scarcity on islands and other areas with limited access to fresh, clean drinking water.

INTRODUCTION

An increasing population and ongoing pollution of surface water systems have made potable water scarce, and set the world in a profound environmental crisis. However, one solution to the clean water shortage is an ecofriendly and efficient way of purifying both polluted water and salt water. This method may, like the ongoing energy crisis, be solved by the sun. Water purification systems can be designed to use the sun's heat to evaporate water and therefore purify it of chemicals and sediments. These systems are completely ecofriendly and yield enormous amounts of potable water if used on a large scale, all while using the abundant, naturally available energy from the sun.

Water scarcity is an increasingly concerning problem. It is currently estimated that approximately 800 million people do not have access to clean drinkable water (Markham, 2014), 1.2 billion people live in regions of physical scarcity or regions without much access to freshwater (United Nations, 2007), and 1.6 billion people, or a quarter of the world population, face economic water shortage (United Nations, 2007). These statistics by themselves resonate concern, but it is still worth considering the implications of not having water. Water is central to health and the existence of life. Humans cannot survive without water. Furthermore, potable and usable water constitutes only approximately 0.007% of the world's water (Shiklomanov, 1993), which highlights the need and importance of developing water purification systems to broaden the quantity of potable water. If the amount of potable water could be doubled simply by purifying salt water, then nearly one-fourth of the world's population could see an increase in quality of life.

The twenty-first century has been an era of environmental crisis. From deforestation to pollution to global warming, ecosystems and environments around the world are being destroyed, and thus global awareness to conservation has stirred. One of the most crucial problems that hinders efforts to help conserve the planet is highlighted in the energy crisis. Much of the used energy sources, such as fossil fuels, are both finite and can adversely affect the environment. However, the solution investigated in this study utilizes an energy source that we see and feel everyday; the sun. The sun produces enough energy in one hour to power the planet (Greenbang, 2010) for a whole year and, best of all, it does not harm the environment in any way. Using the sun as a power source is one of the best ways to help the environment.

Utilizing solar energy to purify water is an extremely promising method. However, it is imperative to find the best design of this system in order to maximize purified water yield and minimize the time the purification process takes. This experiment will focus on the purification yields of a trapezoid-shaped system, which only faces one side of the sky. This structure aims to evaporate water the quickest and amplify the sun's rays and heat from the sun using polyethylene as the transparent material on the top and a mirror to amplify the impact of the solar rays and direct additional rays into the purification system. If the model is successful, it could lead to great advancements in the conservation of the planet.

LITERATURE REVIEW

When designing a solar water purification system, it is important to take account of all of its features and parts. The model used in this investigation is classified as a solar still, which consists of a sealed structure, container for the dirty water, and a transparent top to allow the penetration of solar rays into the system. The water is then evaporated out of the dirty water container and allowed to condense on the underneath side of the polyethylene top, where it is directed down the sloped top into a collection basin. The solar still has many design features that can be modified or altered. Therefore, it is important to investigate the advantages of each of them. Every alteration of the conventional model in this investigation is mentioned and the reason is expounded.

Previous studies have looked at the important variables of a solar purification system and demonstrated that a black colored dirty water container increases purified water yield (Kalogirou, 1997; Ayoub and Malaeb, 2014). Kalogirou (1997) conducted a survey on different solar desalination systems and evaluated the cost, primary energy consumption, sea water treatment requirement, and suitability for solar energy utilization of each system. The systems were divided into two separate groups: direct and indirect collection systems. The direct collection system consisted solely of water stills and it was found that productivity and efficiency could be improved by making the water darker using dye or even charcoal. Inclusively, it was found that using more plastic in the construction of the system would be cheaper, lighter and less breakable in the expense of durability. The indirect collection system consists of numerous systems such as: the multi-stage flash, the multiple-effect boiling, the vapor compression, the reverse osmosis and the electro dialysis. Of all the different types of systems for solar desalination, it was concluded that under the established criteria the multi-effect boiling and the multi-stage flash systems were the best to utilize. This survey reviewed some of the criteria that will be tested in the experiment using a water still-type solar desalination model, but in a much smaller scale. The information presented in the survey helps outline some variables that lie in the design of the solar desalination system and provides a foundation for much of the reasoning for deciding the features and characteristics of the model. The survey did not collect information regarding water stills that utilized plastic materials. In addition, the survey did not provide an in-depth discussion of the materials used for the top of the still, for instance, alternatives to polyethylene. In this investigation, a polyethylene top was used, which differed from the survey and could prove to be a variable vital to the efficiency of the system.

Earlier studies also emphasized the importance of a dirty water solution container with a large surface area. Ayoub and Malaeb (2014) conducted a study on solar desalination stills. The investigators tested a new design for a water still in which they implemented a rotating cylinder that increased the surface area of the solution of interest. Not only was the productivity of this design tested, but also the financial feasibility. After reviewing and testing the model, it was found that the increase in surface area increased the purified water yield by 200 to 300 percent and the cost per unit water became comparable to other desalination methods. The fact that the increase in surface area increased purified water yield supports the decision to use a dirty water container that maximizes surface area. Also, this study strongly considered the cost and accessibility of resources when designing and making the model. The model used in this study consists of inexpensive, locally available materials that will likely be available in regions where economic water scarcity is present. For example, the top of the solar still in the study by Ayoub and Malaeb (2014) was plexi-glass and the one in this study is polyethylene, which is a significantly cheaper and may produce a similar yield of purified water. Therefore, the model developed and tested in this study may be a practical option for a population of nearly any region.

Omara, Kabeel and Younes (2014) explained the impact of a reflector to a solar still and provided some insight into the importance of a large surface area. Their study used steeped solar stills with interior and exterior mirrors to test the effectiveness of the solar desalination system. In addition to testing this new design for a solar still, the investigators tested a conventional solar still to directly compare the results. It was found that the steeped solar stills with interior and exterior reflectors were 125 percent more productive that conventional solar stills. It was concluded that the introduction of these reflectors increased the intensity of the light that fell upon the water solution and therefore introduced more heat into the model. Furthermore, the steeped structure divided the water solution into different compartments, increasing surface area and reducing the brine depth, which is responsible for an increase in purified water yield. Likewise, this study will utilize a mirror to increase purified water yield. However, this study differs from the study by Omara, Kabeel and Younes (2014) since it will investigate the effectiveness of a mirror inside the still, only.

All of these sources help provide a foundation of key characteristics of the solar desalination model used in the investigation. The surface area of the dirty water container used in this study was maximized in order to make the system as efficient and productive as possible. Also, the container was covered with black plastic and the sides of the model with black tape to make the water evaporate more quickly, in addition to a mirror being placed inside the model. All of these features would be mere speculation without the support and findings of the previous studies described above.

METHODOLOGY

The design for the solar desalination system was developed and the materials needed for the construction of the design were purchased from local hardware stores. The materials included one 29 qt. (27.5 liter) plastic storage container with the dimensions of 16.7 inches long by 12 inches wide by 13 inches tall, black masking tape, mirror construction adhesive, and black trash bags. Other materials were bought in a local store and these were polyethylene clear wrap and an aluminum baking pan with dimensions of 12.7 inches long by 8.9 inches wide by 1.9 inches tall. The 8 inch by 10 inch mirror for the model was ordered from a local mirror shop. The majority of the materials were already present in the lab and these were scissors, ruler, utility knife, graduated cylinder, 500 mL beaker, black marker, piece of 2 inch diameter PVC pipe, and ratcheting PVC pipe cutter.

After acquiring all necessary materials, the black marker was used to mark the container where the incision would take place. On one of the 16.7 inch sides, a line was traced 2 inches above the bottom of the container from the start of the side to the end. On the other side of the container, a line was traced that was 3 inches below the top of the container. On both of the 12 inch sides, a diagonal line was traced connecting where the other lines ended. Then, the utility knife was used to cut over the traced line separating the bottom part of the container (Figure 1). Subsequently, a 20-inch long polyethylene clear wrap piece was cut using the scissors and then placed tightly over the area without the bottom of the container. Next, the black masking tape was used to maintain the clear wrap in its tight and sealed position by taping the end of each piece to the container. Then, the black tape was used to cover the sides of the container. After that, the 8 inch by 10 inch mirror was glued, using the mirror constructive adhesive, to the 16.7-inch long side on the container that had a line traced 2 inches from the bottom. The mirror was placed as close to the side of incision as possible but centralized to the sides. Later, the cover lid of the container was taken and, using the utility knife, all plastic separators on the edges were carved out to allow the water to run through. A drill was then used to make three holes on one corner of the cover lid, each separated by half an inch to allow drainage and collection of the condensed water. Furthermore, two 2-inch long PVC pieces were cut from a 2-inch wide PVC tube. A black thrash bag was taken and an 18 inch by 15 inch piece was removed. The trash bag piece was then used to cover the top and sides on the aluminum baking pan (dirty water container) and the sides were then taped to the bottom of the pan with black tape (Figure 2).

After assembling the model, the system was placed under sunlight with the drainage holes overhanging the edge of the surface to allow gravity flow to the collection container. One of the 2-in long PVC pieces was placed under the corner opposite to the corner with the holes to provide sufficient slope to the collection point. Next, using the beaker, 500 mL of tap water were measured and poured into the aluminum baking pan and then the pan was placed over the center of cover lid. The 500 mL beaker was then placed below the corner with the holes and the container was placed over the cover lid.

With the assembly of the model finished and placed under sunlight, the model was left under sunlight for three hours. After the three hours, the model was disassembled and taken back to the lab where the amount of water in the beaker was measured using a graduated cylinder, data written down, and then disposed of. The model was assembled, placed in the sun and data collected two additional times.

Figure 1
Solar still during construction.

Table 1 shows the results from the experiment. After three days of placing the model under the sun for three hours, no water was collected in the beaker on the first two days and only 1.4 mL on the third. These results imply either a deficiency in the ability of the solar desalination model to capture the purified water or to evaporate effectively the water solution in the container inside of it.

Figure 2
Complete solar still during one of the experimental runs.

Table 1
Volume of water (mL) collected from each experimental run.

Water Collected per day (3 hours)	
Day #	amount of water collected (mL)
Day 1	0
Day 2	0
Day 3	1.4

FINDINGS

The results of the experiment can be explained by a series of design issues. The polyethylene clear wrap was held firm by black tape from the outside on the model, but through the inside water was captured in pockets in the union between the clear wrap and container thereby keeping the purified water from reaching the collection beaker. Another issue is that most of the water transported down the sides accumulated on the bottom of the sides and did not run down to the corner, thus the inclination of the model was not drastic enough to force the water to the corner in the holes were located. In addition, the baking pan was very wide to increase surface area, which in theory helps evaporate water faster, but may have been too wide that some water could have fallen back into the container.

The results may indeed bring up the question of the effectiveness of the model in evaporating water. Such reasoning can be discarded, since through monitoring of the model we could observe the water solution condense and droplets of water run down into the sides from the polyethylene clear wrap. In addition, it was observed that out of 500 mL that were initially poured on the pan, the amount of water remaining on the aluminum baking pan after the three hours was 400 mL, thus indicating a significant rate of evaporation. Also, the amount of water in the container was measured the third day and found the same results of 400 mL left as had been left in the container the second day. So even if the model's design is flawed in capturing the purified water, the model was successful in purifying water solution at a reasonable rate.

CONCLUSIONS

The trapezoid-shaped solar still system with the interior mirror, wide container for water solution, and polyethylene clear wrap was not more efficient than a conventional model. This is due to certain design failures in the drainage of the purified water and could be corrected with better sealing between the polyethylene clear wrap and sides of plastic container, a higher slope for the cover lid so that the water runs down easier, and a water solution container not as big. Even though the solar purification system proved to be effective in evaporating water, it is useless if it does not collect the purified water. However with a fix in the design, the model could mean a cheap, mobile solution for water scarcity in places such as islands where there is no access to fresh water, but to salt water. Additionally, it would be an energy independent model that would help the environment while saving money and resources.

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